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Inter-organisational green packaging design: a case study of influencing factors and constraints in the automotive supply chain

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Green packaging is playing an increasingly important role in greening the supply chain. However, the issues that companies face when developing green packaging solutions for the transportation of products within supply chains are poorly understood. A case study of an automotive component manufacturer is presented that explores the complexity of the decisions that surround the decision of inter-organisational packaging design. Drawing upon the literature, legislation and the expert evaluation provided by the case organisation, it identifies the important criteria that influence packaging design and comprise customer requirements, legislation, operational and environmental concerns. This research finds that even though the company makes significant efforts to improve its environmental performance, operational concerns are most influential factors in the design of packaging. Initiatives that aim to improve the environmental performance of packaging are also constrained by external influences in the supply chain, such as customer pressure to adopt branded packaging systems and the inability to influence the design of incoming goods and material packaging.

Keywords: packing problems; supply chain management; case study; fuzzy AHP; fuzzy TOPSIS

1. Introduction

The issue of sustainability is one that is of concern to society and has become increasingly important to most businesses. The Brundtland Report (1987) defined sustainability as the ability to meet the needs of the present without compromising the needs of the future. In raising awareness of the sociological, institutional and economic dimensions of our collective environmental impact, sustainability has been placed onto the political agenda. This and subsequent reports spurred the introduction of a broad range of legislation to ensure that organisations contribute to efforts to reduce their immediate and long-term impact upon the environment. Following EU Directive 94/62/EC made in 1992, the United Kingdom implemented the Producer Responsibility Obligations (Packaging Waste) Regulation 1997 and Packaging (Essential Requirements) Regulation 1998. Administered by the Environment Agency in England and Wales and the Scottish Environmental Protection Agency in Scotland, the regulations aim to drive the reduction and recovery of packaging materials by packaging producers and by those organisations that use packaging to transport products (Environment Agency 2013).

The UK produces around 10 million tonnes of packaging waste per annum, much of which is ultimately disposed of via landfill but which could be recycled (Gateway 2013). As environmental issues continue to be of concern to the wider public (DEFRA 2013), the reduction of packaging waste is likely to be an important and demonstrable aspect of an organisation's commitment to be socially responsible. Successive revisions to the regulations have sought to not only make targets for waste reduction more challenging but also reduce the impact of the regulations on small to medium enterprises (SMEs): currently, only those businesses with a turnover in excess of £2 million and over 50 tonnes of packaging handled per annum are required to comply.

It remains though a complicated undertaking for many organisations to which the regulations still apply. In brief, the packaging regulations require that a company demonstrates and reports that it is reducing the amount of packaging that is used, minimising the presence of hazardous materials and maximising packaging material reuse and recycling. In order to do this, it is necessary to accurately, and continually, record all packaging materials that are received and used by the company. The control and minimisation of packaging materials and packaging waste is therefore a key component of an organisation's sustainability initiatives. In order to understand how companies handle the decision-making process around inter-organisational packaging, the research questions in this paper are as follows:

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(1) What are the key factors influencing design of effective inter-organisational packaging solutions?
(2) How do companies balance the sustainability objectives and operational needs when making inter-organisational packaging decisions?

To answer the questions, a real-world case study is presented to help researchers and practitioners to understand the decision-making process of inter-organisational packaging design from a practical point of view. Multiple criteria decision analysis (MCDA) methods including fuzzy analytical hierarchical process (AHP) and a fuzzy extension of the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) are employed to perform structured analysis of decision criteria and evaluate alternative solutions for green inter-organisational packaging. Such an approach enables to understand the complexity of internal and external pressures that influence the packaging design and the trade-off between the competing needs of operational and environmental objectives.

The rest of the paper begins with a review of the literature that explores the design and use of packaging materials. It critically examines the development of the research that has tended to focus upon packaging that is provided directly to the consumer and has omitted the exploration of packaging that is designed for inter-organisational transport of products. Following this, the case study methodology is then presented that details the approach for capturing the green packaging design criteria in the case organisation. It then explores the organisation's approach towards managing and developing packaging design for the movement of products between sites in a manufacturing supply chain. Next, the findings are reported and finally a critical discussion of the case study is provided before the concluding remarks are given.

2. Literature review

2.1 *The role of packaging*

The review of the literature around packaging material design reveals that a large proportion of research has been concerned with its aesthetics, function and the role of packaging to influence consumer purchasing behaviour (e.g. Argo and White 2012; Carse, Thomson, and Stansfield 2010; Levin and Levin 2010; Venter et al. 2011). Some of this literature recognised the environmental dimension of packaging design but still tended to adopt a consumer perspective (Aydinliyim and Pangburn 2012; Rokka and Uusitalo 2008).

It has long been recognised, however, that packaging materials have a much broader purpose than simply attracting consumers (Carter and Ellram 1998; Hise and McNeal 1988). Hise and McNeal (1988) noted that packaging is also designed to facilitate stackability, to enhance product lifespan and to protect contents from damage. Corey and Bone (1992) later called for further research into the ethics of packaging, observing that a great many internal and external factors influence packaging designs and solutions, yet they also concentrated upon packaging that was intended for consumers. Even relatively recently Verghese and Lewis (2007) commented that the literature has tended to focus upon packaging that is intended for consumers and had largely ignored the packaging of materials that are transported between industrial organisations. Lately, Simpson (2010) also noted that the management of 'secondary wastes' such as packaging is an under-researched area. Despite this, contemporary studies still focus upon packaging that is intended for consumers (Avittathur and Shah 2004; Das 2012; Dowlatshahi 2000; Qalyoubi-Kemp 2009).

This tendency to overlook the importance of inter-organisational packaging issues may be explained, at least in part, by Nunan's (1999) overview of the policy and practice that surrounded the introduction of the packaging regulations in the United Kingdom. She noted that while packaging material producers, fillers and retailers formed part of the advisory groups that shaped the development of the packaging regulations, there was no mention of the groups containing any representation from manufacturing or other sectors. The lack of representation of industrial organisations, or those that do not package products directly for retail or the consumer, is indicative of systemic consumer myopia in both research and policy-making. No doubt this has been largely induced via consumer-lead pressure for improved environmental performance and reductions in packaging materials (Corey and Bone 1992; Kassaye and Verma 1992; Verghese and Lewis 2007).

2.2 *Inter-organisational packaging*

The impact of inter-organisational activities upon the environment has recently begun to attract academic attention. Concepts such as green supply chain (GSC) and green supply chain management (GSCM) have emerged in an attempt to clearly identify this field of research. For instance, GSCM has been examined in several national contexts, including Canada and the United States (Labatt 1997; Vachon 2007), the United Kingdom (Bhattacharya et al. 2014), Turkey

(Tuzkaya, Gülsün, and Önsel 2011) and China (Huang, Tan, and Ding 2012), as well as in comparative studies of countries (Vijayvargy and Agarwal 2013).

Routroy (2009) highlighted the importance of the GSC in developing a sustainable business, and several studies have highlighted the importance of the procurement function in the development of GSC (Hollos, Bome, and Foerstl 2012). Routroy (2009) specifically mentioned packaging as a key source of environmental waste and identified initiatives that had resulted in considerable improvement in environmental performance. Lewis (2005) drew together different perspectives on packaging, product stewardship and sustainability in his study on the Australian packaging industry. The research shows that the packaging industry would benefit from greater consensus about how it should design and manage packaging to meet community expectations about sustainability. Lee and Xu (2005) presented a general overview of sustainable product packaging including the life cycle assessment of packaging systems and new, innovative environmental friendly packaging materials. Siracusa et al. (2008) provided a comprehensive review that offers a complete view of the state of the art on biodegradable polymers for food packaging. Focusing on the fast food industry, Aarnio and Hämäläinen (2008) examined the problem of recovery of packaging waste. Their research indicated that there is potential to tackle the problem, but it demands cooperation between the fast food industry, the waste management sector and public authorities. From a life cycle perspective, Williams, Wikström and Löfgren (2008) explored different ways of reducing the environmental impact of the food packaging system in order to increase customer satisfaction. Using a similar concept, Svanes et al. (2010) proposed a holistic methodology for sustainable packaging design that considers both packaging and the packaged products across the life cycle from raw material extraction to the waste phase. Furthermore, Grönman et al. (2013) proposed a guiding framework for designing sustainable food packaging, in which the entire life cycle of the product–package combination is taken into consideration.

2.3 *Benefits and challenges of packaging reduction*

Recently, Gnoni, Felice, and Petrillo (2011) identified that improving the efficiency of packaging is an important strategic goal for organisations, and it is one that can result in significantly improved environmental performance (Hollos, Blome, and Foerstl 2012). Some studies have developed approaches to ascertaining the value of handling product and waste returns (Dowlatshahi 2010; Haas, Murphy, and Lancioni 2003; Teunter 2001). The benefits of implementing effective GSCM, however, are not entirely clear. Richey et al. (2004) for instance found that effective reverse logistics can provide economic benefits, while Vijayvargy and Agarwal (2013) concluded that it can produce operational, environmental and financial benefits. Franey, Okrasinski, and Schaeffer (2010) examined the design of packaging to improve product reliability and environmental performance in the information technology sector and also found that packaging design can provide substantial cost and environmental benefits as well as improved product protection.

Studies have indicated that the decisions around the design of packaging are more complicated than simply selecting the most optimum environmental solution. In fact, environmental concerns appear to be merely a small portion of the totality of pressures that are exerted on an organisation. These pressures comprise internal operational issues, including organisational culture, functional prerogatives, product integrity and quality, employee safety and ergonomics, but above all, cost concerns (Corey and Bone 1992; Franey, Okrasinski, and Schaeffer 2010; Kassaye and Verma 1992; Matthews 2004; Routroy 2009; Tsai and Hung 2009). Other significant pressures arise from external sources including consumers and pressure groups, upstream and downstream supply chains especially customers and packaging producers, the presence of supporting infrastructure and the government (Corey and Bone 1992; Dharmadhikari 2012; Kassaye and Verma 1992; Labatt 1997; Matthews 2004; Routroy 2009; Saen 2011; Verghese and Lewis 2007). The complexity of the decisions is further exacerbated by having to contend with legislation that decrees the packaging that is required for particular categories of products, such as explosives, fissile materials and foodstuffs, and even by the need to contend with subjects such as the elimination of pests and insects from wooden packaging materials (Chen, White, and Robinson 2006; Molina-Murillo et al. 2005; Slahor et al. 2005).

2.4 *Summary*

Environmental issues continue to be a subject of interest to the stakeholder society and are consequently of great concern to organisations. Through the reduction and elimination of supply chain wastes organisations can make immediate improvement in their environmental performance that may also result in improved operational and financial performance. The reduction of waste in the packaging of materials and products is a key area of company operations, not only because it is strategically significant and capable of providing considerable bottom line benefits, but also because it is a legislative requirement for the majority of organisations. Despite this longstanding recognition of its importance, comparatively little work has been undertaken to understand the way that packaging solutions are developed within supply chains and the impact that those solutions have upon the remainder of the supply chain. This paper endeavours to address the gap in the literature by undertaking a case study examination of an automotive SME in order to explore the complexity of the decisions that need to be made when developing green packaging solutions. It examines the internal and external pressures that conspire to dictate and constrain the packaging solutions that are developed for the transport of products between organisations in a supply chain. The study presents a detailed examination of the development of a packaging solution for a hydraulic braking product.

3. Methodology

Since inter-organisational green packaging design is a relatively new research area, a case study method is appropriate because of its ability to generate the type of knowledge that cannot be gleaned from purely analytical or statistical analysis (McCutcheon and Meredith 1993; Meredith et al. 1989; Yin 1994). It is especially suitable for studying phenomena in highly complicated contexts (Stuart et al. 2002). Employing the case study approach provides a unique opportunity to understand the packaging practices of the case organisation in their entirety without necessarily isolating them from their context (Hartley 1994).

3.1 *Case selection*

Case selection often plays an influential role since the selected case(s) will have to provide valid information to support the theory building and explanation. A single case is used as the basis of this study. Many academics support the view that the use of multiple cases is likely to create more robust and testable theory than single case research since multiple cases can augment external validity and help guard against observer bias (Barratt, Choi, and Li 2011; Eisenhardt and Graebner 2007; Yin 1994). Voss, Tsikriktsis, and Frohlich (2002) countered this view by arguing that fewer numbers of cases provides opportunity of depth of observation. Dyer and Wilkins (1991) suggested that single case studies enable the researchers to capture in much more detail the context within which the phenomena under study occur.

The case organisation operates in the automotive sector employing around 2000 people across ten manufacturing sites in the USA, Europe and Asia. It is a manufacturer of heavy-duty safety-critical braking products for large original equipment manufacturers (OEM) and many aftermarket customers around the world. This study is made within the UK-based manufacturing facility that employs around 250 staff.

3.2 *Data collection and analysis*

The case analysis has three objectives. First, we try to gain a broad understanding of the role of green packaging in the company's product and service value proposition and the impact of green packaging practices on operational performance. Second, we intend to identify the key criteria that influence managers' decisions around green packaging solutions. Third, we aim to explore the insights of how the managers manage the dilemmas associated with competing stakeholders and sort out possible trade-offs to make packaging decisions.

To achieve the objectives, data for the empirical inquiry were obtained over a three-month period. First, approximately twenty hours of on-site observation was carried and instantaneously sampled field notes were compiled during the observation (Paolisso and Hames 2010). This supported the acquisition of a thorough understanding of the organisation's packaging operation. In addition, semi-structured interviews were deployed as the main data collection method. Within the facility, all members of the packaging operation team and the operations, quality and warehouse managers were interviewed. A total of 15 interviews were conducted. All interviews took place on site with interview time ranging from 45 min to an hour. Interviews were digitally recorded and transcribed. Unclear answers were clarified through email or through follow-up questions in subsequent rounds. In order to ensure the reliability and validity, in addition to the data collected through interviews, managers from the case company were asked to review the draft case study report.

To understand the role of green packaging practices in the company's business model, we asked how green packaging practices are adopted in its internal operations and supply chain management. Information about the history and evolution of environmental friendly packaging practices was also gathered to explicate managerial motives and company strategy. In order to identify key decision criteria for packaging solutions, interviewees were asked to provide key factors that affect their decisions in the evaluation of packaging solutions. Key words extracted from the interview scripts were categorised to form a green packaging evaluation decision framework. MCDA approaches were then applied to identify common themes as to how managers handle information uncertainty, make trade-offs and balance the potentially competing needs to be profitable and environmentally sustainable. More specifically, fuzzy AHP was used to derive the importance weights of decision criteria, and fuzzy TOPSIS was utilised to rank alternative packaging solutions. Both FAHP and fuzzy TOPSIS utilise the advantages of fuzzy set theory that can incorporate imprecise information and uncertain variables when conducting pairwise comparison of decision criteria and evaluating alternative solutions. The two methods have been widely applied in many management areas such as supplier selection (Kumaraswamy et al. 2011), evaluation of new product design (Chan and Wang 2013) and risk assessment (Samvedi, Jain, and Chan 2013). The mathematical procedures of FAHP and fuzzy TOPSIS and their applications have been well reported in the literature. A more detailed analysis of the theoretical foundations of these methods and their applications can be found in the comprehensive reviews conducted by Ho (2008), Ho, Xu, and Dey (2010), and Behzadian et al. (2012). In this paper, the mathematical steps of the two MCDA methods are only presented in the Appendix 1.

4. Findings

4.1 *Company overview*

The organisation considered in this case study is an SME that designs and manufactures hydraulic braking products for several large automotive OEM. The majority of the company's products comprise precision-machined iron castings, featuring hydraulic seals and actuating assemblies. Consequently, they require protection from water ingress and rusting, damage to seals and machined surfaces, and contamination from dust and grit. Many also contain hydraulic fluid and the packaging must therefore be capable of preventing any leakage from contaminating other nearby products during transport or from causing a slip hazard.

Most of the organisation's OEM customers stipulate the way that products must be packaged and transported. These are captured in the form of formal packaging specifications and are a contractual obligation. These specify the precise amount and type of materials that are used to package the product. Often, these will also specify that the customer's own, branded, returnable packaging containers are used. Some customers also specify the method of packaging, most, however, make less stringent demands and merely state that the product must be packaged in a manner that ensures that it is protected from damage during shipping and that standards of cleanliness and functionality are maintained.

The organisation's products comprise a variety of components that are machined and assembled in-house. The majority of bought-out materials and components comprise metal castings, forgings, screws, washers and seals. These are sourced from locations around the globe. Many of these suppliers are large enterprises for whom the case organisation forms a very small proportion of their overall business. The mode of packaging of incoming goods is therefore dictated by the supplier and the method of transport: sea-freight, for example, requiring additional protection from corrosion, and the transportation of heavy metal castings and forgings requires robust packaging and tends to favour bulk deliveries. Many high-volume, small components are dual-sourced or procured on an 'as needed' basis, and these will be packaged in a variety of ways according to the supplier, the volume ordered and the method of transport.

As part of its commitment to complying with the regulations and to continually improving its environmental performance as required by its ISO14001 certification, the organisation has introduced several waste reduction initiatives. First, it makes good use of incoming packaging materials, carefully unpacking incoming goods and storing the packaging materials on site. Reusing incoming packaging materials aids in reducing the amount of materials that are introduced to the packaging supply chain and is a key requirement of the packaging regulations. The outgoing packaging materials that can be used therefore depend upon the availability and the dependability of their incoming supply. Disassembling the incoming packaging, while resulting in the opportunity to reuse many of the materials, is a considerable cost to the organisation. For instance, those reclaimed materials can require considerable storage space.

As a small customer to many of the castings and forgings manufacturers, the organisation is not able to specify the packaging specifications for incoming goods. This means that the incoming supply of potentially reusable packaging materials is unpredictable. Consequently, the organisation is unable to engage in forward planning of packaging material procurement, resulting in large stocks of unused materials on occasions. Furthermore, its own packaging function then lacks the ability to develop consistent packaging specifications and ways of working. This results in greater operational inefficiencies.

4.2 *Case analysis*

This section concentrates on the decision-making on the packaging solution of an example product from the case organisation that is referred to as a 'booster'. The booster is manufactured in the United Kingdom and supplied to a large customer based in mainland Europe, since the customer is based in the EU Producer Responsibility Obligations (Packaging Waste) Regulation 1997 and Packaging (Essential Requirements) Regulation 1998 apply. This is a relatively low-volume product, and the customer does not stipulate a packaging specification, but does require that the booster should arrive in 'clean, working condition without damage or degradation'. Being a low-volume product, the organisation is acutely aware of the implications of specifying expensive and complex packaging. However, it is essential to maintain high standards and impressions of quality.

4.2.1 *Decision framework for green packaging design*

The literature clearly points out that the design and development of packaging material can have a significant effect upon an organisation's environmental performance but may not be a simple undertaking. This case indicates that the design choices can be highly complex and influence operational and quality performance as well as environmental performance. In addition to legislative requirements, efforts to improve packaging can be influenced by many internal and external forces. Through the interviews with the operations manager, quality manager and warehouse manager of the case company, the choice of product packaging designs can be categorised according to four major influences including customer-imposed requirements, regulatory and legislative requirements, operational objectives and environmentally motivated initiatives. Moreover, key criteria within each evaluation category were identified (see Table 1).

Customer-imposed requirements comprise those situations where large or dominant customers impose packaging specifications upon their supply base. This may be in the form of insisting upon the use of their own, sometimes branded, packaging crates, boxes and other materials. Alternatively, other customers may be less strict in their requirements for the packaging of products and simply request that the supplier take adequate precautions to ensure that the product arrives in clean, undamaged condition. In this case, the evaluation criteria in the customer requirements category include rust free, damage free, contamination free, easy to unpack and minimal material.

The packaging regulations themselves require that eligible organisations minimise the materials that they introduce into the packaging supply chain and promote the reuse, recovery, recycling, composting or biodegrading of materials. Furthermore, there are restrictions upon the nature of materials that may be used, in particular heavy metals, and the organisation is compelled to report the materials that they reclaim, recycle or remove to landfill. In addition to the regulations that aim to reduce the impact of packaging materials upon the environment, specific regulations exist that stipulate the packaging requirements for products that are, for example, explosive, hazardous or for consumption. In this case, the regulatory criteria include reusable, recoverable, recyclable, compostable and biodegradable.

Table 1. A hierarchical model for the evaluation of alternative packaging options in the case company.

Goal	Evaluation category	Evaluation criteria	Packaging options
Select green packaging solution	C_1 Customer	C_{11} Rust free	A_1 Packaging Option 1
		C_{12} Damage free	A_2 Packaging Option 2
		C_{13} Contamination free	A_3 Packaging Option 3
		C_{14} Easy to unpack	A_4 Packaging Option 4
		C_{15} Minimal material	
	C_2 Regulatory	C_{21} Reusable	
		C_{22} Recoverable	
		C_{23} Recyclable	
		C_{24} Compostable	
		C_{25} Biodegradable	
	C_3 Operational	C_{31} Labour cost	
		C_{32} Material cost	
		C_{33} Product Quality	
		C_{34} Availability of packaging material	
	C_4 Environmental	C_{41} Consumption of energy and other resources	
		C_{42} Emission to air, water or soil	
		C_{43} Anticipated pollution	
		C_{44} Generation of waste material	
		C_{45} Improvement of re-use, recycling, and recovery of materials and/or of energy	

The nature of the organisation also introduces operational constraints upon the design of packaging. These are many and varied and may change over time, but typically can include labour and material cost pressures, the design of safe and efficient working systems, the type of transport that is used, the availability of packaging materials and the specific quality requirements of the product that is being packed. Recognising that packaging design is highly situation-specific (Mollenkopf et al. 2005), these criteria do not represent an exhaustive list but are pertinent to the case organisation and are typical examples that may be experienced in other industrial organisations. According to case company circumstance, four operational criteria were identified including labour cost, material cost, product quality and availability of packaging material.

Finally, any environmental initiatives may also introduce constraints upon the design of packaging solutions. One way in which continual improvement in environmental performance can be achieved and demonstrated is through efforts to reduce energy consumption. This can be undertaken by reducing the energy that is consumed during the production and use of the materials, consideration of the resultant emissions to air and to water, any anticipated pollution, the generation of waste materials and the possibility of reusing, recycling and recovery of materials and their constitutive energy. Here, the environmental criteria associated with the green packaging decision include consumption of energy and other resources, emission to air, water or soil, anticipated pollution, generation of waste material, improvement of reuse, recycling and recovery of material and/or of energy.

4.2.2 *Green packaging design evaluation*

After selecting the evaluation criteria, it is important to determine the weights of the decision criteria. The relative importance weights were calculated using the FAHP method illustrated in the Appendix 1. Evaluation questionnaires were completed by the managers of the company, and the results are summarised in Table 2. The final weight scores give an indication of the importance of the factors that influence green packaging decisions for the case organisation. As illustrated, the primary issue of concern is that of cost, mainly that of the cost of labour involved in performing the packaging operation, closely followed by the cost of the packaging materials themselves. Consequently, the company valued relatively 'simple' packaging materials and methods that would not be time-consuming to use nor expensive to procure. Similarly, reusable packaging was preferred, predominantly due to its cost advantage, whereas its environmental benefit was considered to be of secondary importance. Recognising the safety-critical nature of the product, and the prestige customer, product integrity and quality are also rated as highly important.

Historically, the booster has been packaged in four different ways, shown to the right of Table 1 and detailed in Table 3, according to the cost and availability of materials, and the preferences of the staff undertaking the packaging

Table 2. Relative importance weights of decision factors with respect to green packaging.

Category	Weights	Description	Local weights	Final weights	Rank
C_1 customer	0.238	C_{11} Rust free	0.163	0.039	11
		C_{12} Damage free	0.293	0.070	5
		C_{13} Contamination free	0.177	0.042	10
		C_{14} Easy to unpack	0.242	0.058	7
		C_{15} Minimal material	0.125	0.030	15
C_2 regulatory	0.213	C_{21} Reusable	0.360	0.077	4
		C_{22} Recoverable	0.205	0.044	9
		C_{23} Recyclable	0.234	0.050	8
		C_{24} Compostable	0.128	0.027	16
		C_{25} Biodegradable	0.073	0.016	19
C_3 operational	0.408	C_{31} Labour cost	0.355	0.145	1
		C_{32} Material cost	0.211	0.086	3
		C_{33} Product Quality	0.286	0.117	2
		C_{34} Availability of packaging material	0.149	0.061	6
C_4 environmental	0.140	C_{41} Consumption of energy and other resources	0.268	0.038	12
		C_{42} Emission to air, water or soil	0.153	0.021	17
		C_{43} Anticipated pollution	0.117	0.016	18
		C_{44} Generation of waste material	0.234	0.033	13
		C_{45} Improvement of re-use, recycling, and recovery of materials and/or of energy	0.228	0.032	14

Table 3. Key features of alternative packaging options.

Packaging solution alternatives	Key features
Option 1	Wrap the booster in volatile corrosion inhibitor (VCI) paper and seal with adhesive tape to provide rust protection, maintain seal integrity and minimal protection from leakage of oil. Insert this into a plastic tube for damage protection
Option 2	Wrap the booster in plastic sheet and seal shut with adhesive tape to provide limited rust protection, maintain seal integrity and minimal protection from leakage of oil. Wrap in bubble wrap for damage protection
Option 3	Enclose the booster in a sealable plastic bag to provide rust protection, maintain seal integrity and provide good protection from leakage of oil. Insert this into a plastic tube for damage protection
Option 4	Enclose the booster in a sealable plastic bag and wrap in bubble wrap to provide rust protection, maintain seal integrity, good protection from leakage of oil and damage protection

operation: typically, this decision was determined according to what was considered the ‘easiest’, and not necessarily the ‘best’, cheapest or most environmentally sound way to package the booster. All options need be contained in cardboard boxes, of any available size, and placed into either a metal pallet or shrink-wrapped onto a wooden skid. Metal pallets offer the benefit of added damage protection but are also heavy and expensive to return empty because of their low packing density. Wooden skids offer the advantages of being relatively light, reusable, returnable, recyclable and biodegradable after reclaim (to remove the nails used in their construction). Both metal pallets and wooden skids require shrink-wrapping to afford weather protection to the cardboard boxes.

Next, questionnaires were given to the three decision makers for the evaluation of the four alternative packaging design options. Participants were asked to rate the four alternative package designs with respect to all the evaluation criteria. Then, fuzzy TOPSIS (see Appendix 1) was applied to evaluate the alternative package design options, and the results are presented in Table 4. Among the four alternative packaging solutions, Option 3 (A_3) has the highest relative closeness index and was therefore recommended as the preferred packaging solution.

The results in Table 4 also show that the gap between the relative closeness index values of Options 3 and 4 is not significant at all. To understand the rationale behind the decision, further analysis was carried to compare the weighted performance ratings against four evaluation categories between the top two packaging options. The analysis results are described in Figure 1, in which both options exhibit similar performances in the customer and regulatory categories. Although Option 4 has an edge in the environmental category, Option 3 was recommended as the preferred packaging solution because of its better performance in the operational category. This can be explained by the fact that the managers determined that the operational factors were the most pertinent to this organisation (shown in Table 4 and Figure 2). Options 3 and 4 have their own strengths and weaknesses, but the better performance of Option 3 in the Operational criteria influences the final decision in its favour.

4.3 *Discussion*

This case study examination of an automotive manufacturing SME has indicated the significance of environmental issues, particularly those around inter-organisational packaging, to companies in this sector. For this organisation, product packaging is designed not only to facilitate effective transportation, for example, in the use of customer issued returnable packaging containers, but also to protect the product from damage during transport, to protect the working

Table 4. Linguistic classification of performance evaluation of alternative options and their corresponding triangular fuzzy numbers.

Rating level	Linguistic values	Triangular fuzzy numbers
1	Extremely low performance	(0, 0, 1/6)
2	Very low performance	(0, 1/6, 2/6)
3	Low performance	(1/6, 2/6, 3/6)
4	Medium	(2/6, 3/6, 4/6)
5	High performance	(3/6, 4/6, 5/6)
6	Very high performance	(4/6, 5/6, 1)
7	Extreme high performance	(5/6, 1, 1)

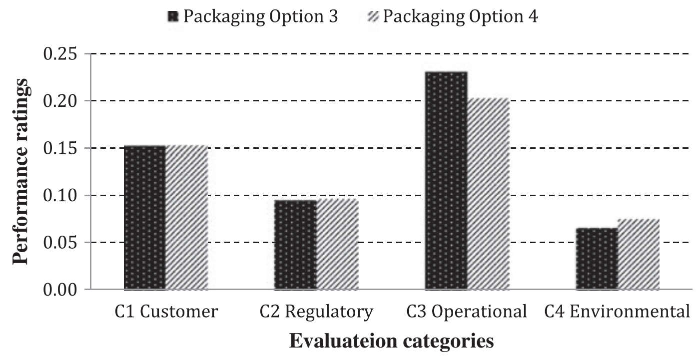

Figure 1. Weighted performance ratings of top two packaging options with respect to main evaluation categories.

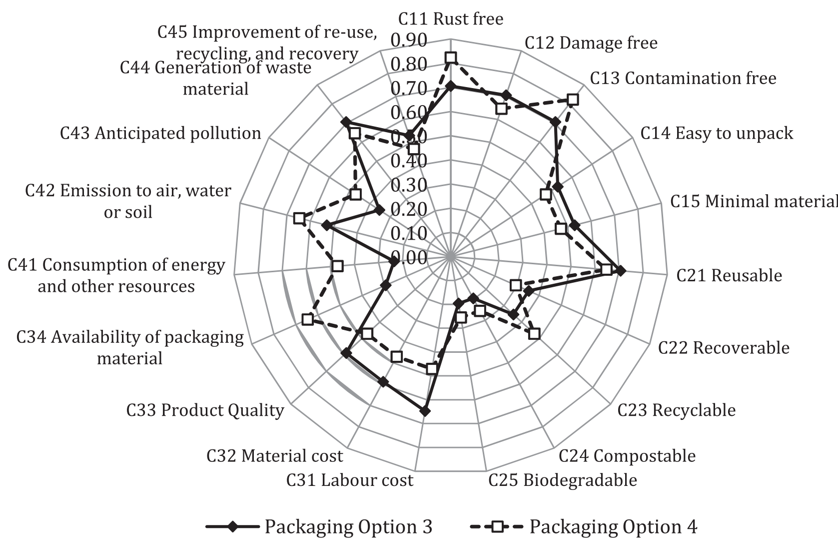

Figure 2. Performance ratings of top two packaging options with respect to evaluation criteria.

environment from hazards such as oil spillages and to imbue a sense of quality service in customers within the supply chain. This illustrates the significance of well-designed product packaging that it used between organisations and not just between retailers and consumers.

Designing effective packaging, however, is not merely a technical issue. Internal pressures and constraints such as the availability of space, dependability of the supply of materials and operational costs all conspire to limit the extent to which the organisation could develop the packaging design to meet cost, quality and performance objectives. Furthermore, external constraints such as customer-imposed specifications, the degree of influence that the organisation has over its supply chain as well as legislative requirements also constrain packaging designs. The benefits of developing effective green packaging solutions are complex and are likely to be situation-specific and difficult to measure (Mollenkopf et al. 2005). However, this case study illustrates how companies take these complex internal and external factors into consideration when evaluating green packaging solutions. In this instance, even though the organisation is making considerable effort to improve its green packaging, the operational factors, most notably cost but also quality, are considered to be more influential upon the design of packaging solutions than its environmental impact.

While initiatives to reuse and recycle packaging materials have obvious environmental benefits, the complexity of the task and the impact that it can have upon operational activities can have deleterious effects upon financial performance. In order to encourage companies to adopt more green packaging solutions, it is important for all the stakeholders throughout the supply chain to work together to achieve this goal. This could be encouraged by customers stipulating green packaging requirements and incorporating environmental performance improvement measures in their packaging specifications. Building upon Simpson's (2010) suggestions, companies that face similar issues to the case company could form local consortia to collaborate on initiatives such as combining purchasing power or to share spare and reusable packaging materials. Regulators can raise the standard of the specific environmental requirements on packaging. However, they must remain mindful of the additional pressures that this would place upon a key sector of the economy that is often already resource constrained.

Companies can incorporate the environmental performance of packaging as an explicit part of their organisational objectives. The promotion of green packaging can bring all parties within the supply chain together to tackle the emerging environmental challenges. Such a practice will not only help to reduce waste and its negative effect upon the environment, but also may even become a significant aspect of the overall environmental strategy of an organisation that has been shown to be capable of attracting new business (White, Lomax, and Parry 2014).

The fuzzy-based MCDA methods, FAHP and fuzzy TOPSIS applied in the case study provide an effective approach that enables to perform structured analysis of decision criteria and evaluate alternative solutions for green packaging. The novelty of the analysis lies in the fact that an analytical tool enables the specific business preferences concerning inter-organisational green packaging design to be taken into consideration in making the packaging decision. The approach that has been used in the context of the case company is flexible enough to accommodate different industry requirements and could be used as a tool guide green packaging decision-making in other organisations and to help managers understand how they prioritise often competing packaging objectives. While recognising its usefulness, the feedback from users also emphasises that there is a need to develop a more robust and user friendly interface in order to promote such tools in supporting green packaging decision-making.

5. Conclusion

The development of inter-organisational green packaging is playing an increasingly important role in improving the environmental performance of supply chains yet it has been the subject of surprisingly little academic attention. This research is based upon a case study of a UK-based manufacturing SME and explores the scope of factors that influence the decisions around packaging specification design. It makes an important contribution to improving understanding of inter-organisational packaging and the factors that influence the design choices.

Despite the increasing interest in environmental performance of packaging solutions, the research finds that operational issues still comprise the most influential decision-making factors in determining packaging solutions, particularly those of labour and material costs along with product quality. In spite of an organisation's intention to continually develop the environmental performance of its packaging, this research also finds that initiatives can be considerably constrained by external factors that are beyond its control. Customer pressures to utilise branded packaging systems may result in their suppliers becoming responsible for recycling, reclaiming or disposing of the extraneous packaging materials that have been previously introduced into the supply chain. This may be compounded by the organisation's position in the supply chain, which, particularly for smaller organisations, may mean that they have little or no influence over the design of packaging of incoming goods and materials. The promotion of green packaging solutions requires the coordinated effort of all stakeholders. Initiatives must take account of the vagaries of commercial sectors and supply chains, recognising that company size, geographical location and relative power in the supply chain all conspire to further the complexity of packaging design.

This paper provides a typology and hierarchy of the criteria that influence packaging specification decision-making. Drawing upon the literature, legislation and the expert evaluation provided by the case organisation it identifies that those decisions are based upon customer requirements, legislation, operational and environmental concerns. Recognising that approaches such as MCDA are not routinely used within organisations, the typology and hierarchy of green packaging decision-making criteria captured in this paper can be used as an initial approach for management to gain an understanding of how they prioritise those criteria and choose between alternative designs. For example, retrospective evaluation of existing packaging solutions may be undertaken to examine what criteria have been used to drive packaging solution design and this may provide valuable insight into the effectiveness of their environmental management policies and initiatives, particularly in SMEs. Meanwhile, larger organisations, or product-specific research and investigation, may choose to benefit from the deeper analysis that is afforded by employing the MCDA techniques that are described in the paper.

Despite the various advantages outlined in the paper, this study has its own limitations, which imply some fruitful directions for future research. For example, weighting estimation of the decision criteria and evaluation of inter-organisational green packaging design were mainly through the inputs of managers from the case company. One future research direction is to incorporate the view of other supply chain parties into the evaluation and to consider the life cycle of both packaging and the packaged products. Furthermore, examination of the efficacy of collaborative and third-party logistics initiatives in reducing the cost and environmental impacts of packaging designs and solutions would appear to be another potentially productive area of research.

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Appendix 1

Fuzzy AHP

Fuzzy AHP is an extension of conventional AHP. One advantage of fuzzy AHP is that when conducting pairwise comparison, a fuzzy number can be assigned instead of providing a precise numerical value. A fuzzy number is a special fuzzy set, such that $\tilde{N} = \{(x, \mu_N(x), x \in R)\}$, where the value of x lies on the real line $R \rightarrow [0, 1]$. We define a fuzzy number $\tilde{N}$ on R to be a triangular fuzzy number (TFN) and the membership function can be described as follows:

$$\mu_N(x) = \begin{cases} (x-L)/(M-L), \; x \in [L, M] \\ (U-x)/(U-M), \; x \in [M, U] \\ 0, \qquad\qquad\qquad\qquad \textit{otherwise} \end{cases} \tag{1}$$

where $L \leq M \leq U$, L and U stand for the lower and upper value of the support of $\tilde{A}$, respectively, and M denotes to the most promising value. The TFN can be denoted by $\tilde{N} = (L, M, U)$. TFNs N_1, N_3, N_5, N_7 and N_9 are used to represent the pairwise comparison of decision variables from 'Equal' to 'Absolutely Important', and TFNs N_2, N_4, N_6 and N_8 represent the middle preference values between them. The membership functions of the TFNs are shown in Figure A1, $N_i = (L_i, M_i, U_i)$, where $i = 1, 2,\ldots, 9$. This kind of expression is used to compare two assessment criteria by nine basic linguistic terms.

The procedure for standard FAHP has been well documented in the literature, and the following is a summary of the procedures with reference to studies conducted by Hsieh, Lu, and Tzeng (2004) and Wang and Durugbo (2013):

Step 1: Construct pairwise comparison matrices from a panel of experts. Linguistic variables could be used so the following matrix (per expert) is constructed by Equation (2). For simplicity, reference to different experts is omitted (see Step 2):

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & & \tilde{a}_{2n} \\ \vdots & & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} \quad (2)$$

where $\tilde{a}_{ij} = 1/\tilde{a}_{jt}\tilde{a}_{ij} = 1/\tilde{a}_{ji}$

$$\text{and } \tilde{a}_{ij} = \begin{cases} \tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9} & \textit{if criterion i is relatively important to criterion j} \\ 1 & \textit{if } i = j \\ \frac{1}{1}, \frac{1}{3}, \frac{1}{5}, \frac{1}{7}, \frac{1}{9} & \textit{if criterion i is relatively less important to criterion j} \end{cases}$$

Step 2: Since the evaluation of different experts would lead to different matrices, we need to integrate the opinion of different experts to form one synthetic pairwise comparison matrix. Obviously, this step can be skipped if there is only one expert in Step 1. The elements of the synthetic pairwise comparison matrix ($\tilde{a}_{ij}$) are calculated by using the geometric mean method proposed by Buckley (1985):

$$\tilde{a}_{ij} = (\tilde{a}_{ij}^1 \otimes \tilde{a}_{ij}^2 \ldots \otimes \tilde{a}_{ij}^E)^{1/E} \quad (3)$$

The superscript in Equation (3) is the index refers to different experts and there are total of E experts.

Step 3: Make use of the synthetic pairwise comparison matrix from Step 2, define the fuzzy geometric mean ($\tilde{r}_i$) and fuzzy weights of each criterion ($\tilde{w}_i$) using Equation (4) and Equation (5), respectively:

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \ldots \otimes \tilde{a}_{in})^{1/n} \quad (4)$$

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \ldots \oplus \tilde{r}_n)^{-1} \quad (5)$$

Step 4: Since the calculation so far involves linguistic variables, the next step is to defuzzify the weights to form meaningful figures for analysis (e.g. ranking). The centre of area method is used for defuzzification. Assume the fuzzy weights of each criterion (w_i) can be expressed in the following form:

$$\tilde{w}_i = (Lw_i, Mw_i, Uw_i) \quad (6)$$

where Lw_i, Mw_i, Uw_i represent the lower, middle and upper values of the fuzzy weight of the ith criterion. Then, the non-fuzzy (i.e. defuzzified) weight value of the ith criterion (w_i) is given as follows:

$$w_i = [(Uw_i - Lw_i) + (Mw_i - Lw_i)]/3 + Lw_i \quad (7)$$

Fuzzy TOPSIS

TOPSIS is a technique to evaluate the performance of alternatives through the similarity with the ideal solution proposed by Hwang and Yoon (1981). The main concept of TOPSIS is to define the positive ideal solution and negative ideal solution. The positive ideal solution maximises the benefit criteria and minimises the cost criteria. The negative ideal solution maximises the cost criteria and minimises the benefit criteria. The most preferred alternative should have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution. Fuzzy TOPSIS is an extension of conventional TOPSIS method, which makes use of fuzzy logic to deal with uncertain parameters and information. The procedure for fuzzy TOPSIS has been well documented in the literature, and the following is a summary of the procedures with reference to studies conducted by Wang and Chan (2013) and Wang and Durugbo (2013).

To evaluate a set of alternative green packaging solutions, a fuzzy decision matrix, $\tilde{D}$, is first constructed based on a given set of categories and criteria. Referring to the hierarchy framework in Figure 1, there are n alternatives A_k (k = 1, 2,…, n) and four main categories. Each category has c_i criteria where the total number of criteria is equal to $\sum_{i=1}^{4} c_i$. $\tilde{x}_{kij}$ represents the value of the jth sub-criterion within ith main criterion of the kth alternative, which can be crisp data or appropriate linguistic variables which can be further represented by fuzzy numbers, for example $\tilde{x}_{kij} = (a_{kij}, m_{kij}, b_{kij})$. A hierarchical MCDM problem can be concisely expressed in a fuzzy decision matrix as follows:

$$\tilde{D}=\begin{array}{c} \\ \\ A_1\\ A_2\\ \vdots\\ A_n \end{array}\begin{array}{c} \begin{array}{cccccccccccccccc} C_1 & & & & C_2 & & & & C_3 & & & & C_4 & & & \\ C_{11} & C_{12} & \cdots & C_{1c_1} & C_{21} & C_{22} & \cdots & C_{2c_2} & C_{31} & C_{32} & \cdots & C_{3c_3} & C_{41} & C_{42} & \cdots & C_{4c_4} \end{array} \\ \left[\begin{array}{cccccccccccccccc} \tilde{x}_{111} & \tilde{x}_{112} & \cdots & \tilde{x}_{11c_1} & \tilde{x}_{121} & \tilde{x}_{k21} & \cdots & \tilde{x}_{12c_2} & \tilde{x}_{131} & \tilde{x}_{132} & \cdots & \tilde{x}_{13c_4} & \tilde{x}_{141} & \tilde{x}_{142} & \cdots & \tilde{x}_{14c_4} \\ \tilde{x}_{211} & \tilde{x}_{212} & \cdots & \tilde{x}_{21c_1} & \tilde{x}_{221} & \tilde{x}_{222} & \cdots & \tilde{x}_{22c_2} & \tilde{x}_{231} & \tilde{x}_{232} & \cdots & \tilde{x}_{23c_4} & \tilde{x}_{241} & \tilde{x}_{242} & \cdots & \tilde{x}_{24c_4} \\ \vdots & \vdots & & \vdots & \vdots & \vdots & & \vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & & \vdots \\ \tilde{x}_{n11} & \tilde{x}_{n12} & \cdots & \tilde{x}_{n1c_1} & \tilde{x}_{n21} & \tilde{x}_{n22} & \cdots & \tilde{x}_{n2c_2} & \tilde{x}_{n31} & \tilde{x}_{n32} & \cdots & \tilde{x}_{n3c_4} & \tilde{x}_{n41} & \tilde{x}_{n42} & \cdots & \tilde{x}_{n4c_4} \end{array}\right] \end{array}$$

$$k=1,2,\ldots,n;\ i=1,2,3,4;\ j=1,2,\cdots,c_i \tag{8}$$

In general, the criteria can be classified into two categories: benefit and cost. The benefit criterion means that a higher value is better while for the cost criterion is valid the opposite. The data of the decision matrix $\tilde{D}$ come from different sources. Therefore, it is necessary to normalise it in order to transform it into a dimensionless matrix, which allows the comparison of the various criteria. In this research, the normalised fuzzy decision matrix is denoted by $\tilde{R}$ shown as follows:

$$\tilde{R}=\left[\tilde{r}_{kij}\right]_{n\times m},\quad k=1,2,\ldots,n;\quad i=1,2,3,4;\quad j=1,2,\cdots,c_i;\quad m=\sum\nolimits_{i=1}^{4}c_i \tag{9}$$

The normalisation process can then be performed by the following fuzzy operations:

$$\tilde{r}_{kij}=\begin{cases}\left(\frac{a_{kij}}{u_{ij}^{+}},\frac{m_{kij}}{u_{ij}^{+}},\frac{b_{kij}}{u_{ij}^{+}}\right), & \forall_{ij},\tilde{x}_{ij}\ \textit{is a benefit criterion}\\ \left(\frac{u_{ij}^{-}}{a_{kij}},\frac{u_{ij}^{-}}{m_{kij}},\frac{u_{ij}^{-}}{b_{kij}}\right), & \forall_{ij},\tilde{x}_{ij}\ \textit{is a}\ \cos t\ \textit{criterion}\end{cases} \tag{10}$$

where $\tilde{u}_{ij}^{+}$ and $\tilde{u}_{ij}^{-}$ present the largest and the lowest value of each criterion, respectively. The weighted fuzzy normalised decision matrix is shown as follows:

$$\tilde{V}=\left[\tilde{v}_{kij}\right]_{k\times m},\quad k=1,2,\ldots,n;\quad i=1,2,3,4;\quad j=1,2,\cdots,c_i;\quad m=\sum\nolimits_{i=1}^{4}c_i \tag{11}$$

where $\tilde{v}_{kij}=\tilde{r}_{kij}\otimes W_{ij}$.

Here, W_{ij} is the final weight core for each criterion, which is the product of the criterion weight score and the associated main evaluation category weight score as follows:

$$W_{ij}=w_{c_i}\otimes w_{c_{ij}}=w_i\otimes\begin{bmatrix}w_{i1}\\ w_{i2}\\ \vdots\\ w_{ic_i}\end{bmatrix},\quad (i=1,2,3,4) \tag{12}$$

where w_{c_i} and $w_{c_{ij}}$ denote the i^{th} main category weight score and the criterion weight score with respect this main category, respectively. Both w_{c_i} and $w_{c_{ij}}$ are obtained through the pairwise comparison method discussed in Section 3.2. The results of equation 11 can be summarised as follows:

$$\tilde{V}=\begin{array}{c} \\ \\ A_1\\ A_2\\ \vdots\\ A_n \end{array}\begin{array}{c} \begin{array}{cccccccccccccccc} C_1 & & & & C_2 & & & & C_3 & & & & C_4 & & & \\ C_{11} & C_{12} & \cdots & C_{1c_1} & C_{21} & C_{22} & \cdots & C_{2c_2} & C_{31} & C_{32} & \cdots & C_{3c_3} & C_{41} & C_{42} & \cdots & C_{4c_4} \end{array} \\ \left[\begin{array}{cccccccccccccccc} \tilde{v}_{111} & \tilde{v}_{112} & \cdots & \tilde{v}_{11c_1} & \tilde{v}_{121} & \tilde{v}_{122} & \cdots & \tilde{v}_{12c_2} & \tilde{v}_{131} & \tilde{v}_{132} & \cdots & \tilde{v}_{13c_4} & \tilde{v}_{141} & \tilde{v}_{142} & \cdots & \tilde{v}_{14c_4} \\ \tilde{v}_{211} & \tilde{v}_{212} & \cdots & \tilde{v}_{21c_1} & \tilde{v}_{221} & \tilde{v}_{222} & \cdots & \tilde{v}_{22c_2} & \tilde{v}_{231} & \tilde{v}_{232} & \cdots & \tilde{v}_{23c_4} & \tilde{v}_{241} & \tilde{v}_{242} & \cdots & \tilde{v}_{24c_4} \\ \vdots & \vdots & & \vdots & \vdots & \vdots & & \vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & & \vdots \\ \tilde{v}_{n11} & \hat{v}_{n12} & \cdots & \tilde{v}_{n1c_1} & \tilde{v}_{n21} & \tilde{v}_{n22} & \cdots & \tilde{v}_{l2c_2} & \tilde{v}_{n31} & \tilde{v}_{n32} & \cdots & \tilde{v}_{n3c_4} & \tilde{v}_{n41} & \tilde{v}_{n42} & \cdots & \tilde{v}_{n4c_4} \end{array}\right] \end{array} \tag{13}$$

Subsequently, the fuzzy addition principle is used to aggregate the values within each main category as follows:

$$\tilde{v}'_{ki}=\sum_{j=1}^{c_i}\tilde{v}_{kij},\quad k=1,2,\ldots,n;\quad i=1,2,3,4 \tag{14}$$

The matrix $\tilde{V}$ is thus converted into the final weighted normalised fuzzy decision matrix $\tilde{V}'$

$$\tilde{V}' = \begin{array}{c} \\ A1 \\ A2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & C_3 & C_4 \end{array} \\ \begin{bmatrix} \tilde{v}'_{11} & \tilde{v}'_{12} & \tilde{v}'_{13} & \tilde{v}'_{14} \\ \tilde{v}'_{21} & \tilde{v}'_{22} & \tilde{v}'_{23} & \tilde{v}'_{24} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{v}'_{n1} & \tilde{v}'_{n2} & \tilde{v}'_{n3} & \tilde{v}'_{n4} \end{bmatrix} \end{array} \quad (15)$$

This addition operation is important as the hierarchical structure can be reflected only when aggregation of the weighted values within each main criterion is conducted.

Now, let A^+ and A^- denote the fuzzy positive idea solution (FPIS) and fuzzy negative ideal solution (FNIS), respectively. According to the weighted normalised fuzzy decision matrix, we have the following:

$$A^+ = \left(\tilde{v}_1^+, \tilde{v}_2^+, \tilde{v}_3^+, \tilde{v}_4^+\right)$$

$$A^- = \left(\tilde{v}_1^-, \tilde{v}_2^-, \tilde{v}_3^-, \tilde{v}_4^-\right) \quad (16)$$

where $\tilde{v}_i^+$ and $\tilde{v}_i^-$ are the fuzzy numbers with the largest and the smallest generalised mean, respectively. The generalised mean for the fuzzy number $\tilde{v}_{ki} = (a_{ki}, m_{ki}, b_{ki})$, $\forall i$, is defined as follows:

$$M(\tilde{v}_{ki}) = \frac{-a_{ki}^2 + b_{ki}^2 - a_{ki}m_{ki} + m_{ki}b_{ki}}{[3(-a_{ki} + b_{ki})]} \quad (17)$$

For each column i, the greatest generalised mean of $\tilde{v}_i^+$ and the lowest generalised mean of $\tilde{v}_i^-$ can be obtained, respectively. Consequently, the FPIS (A^+) and the FNIS (A^-) are derived. Then, the distances (d^+ and d^-) of each alternative from A^+ and A^- can be calculated by the area compensation method as follows:

$$\tilde{d}_k^{\,+} = \sum_{i=1}^{n} d\left(\tilde{v}_{ki}, \tilde{v}_i^+\right), \quad k = 1, 2, \ldots, n; \quad i = 1, 2, 3, 4 \quad (18)$$

$$\tilde{d}_k^{\,-} = \sum_{i=1}^{n} d\left(\tilde{v}_{ki}, \tilde{v}_i^-\right), \quad k = 1, 2, \ldots, n; \quad i = 1, 2, 3, 4 \quad (19)$$

$$d\left(\tilde{A}, \tilde{B}\right) = \sqrt{\frac{1}{3}\left[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2\right]} \quad (20)$$

By combining the difference distances d^+ and d^-, the relative closeness index is calculated as follows:

$$\tilde{C}_k = \frac{\tilde{d}_k^{\,-}}{\tilde{d}_k^{\,+} + \tilde{d}_k^{\,-}} \quad (21)$$

According the index value, the set of alternative packaging options can be ranked from the most preferred to the least preferred feasible solutions.

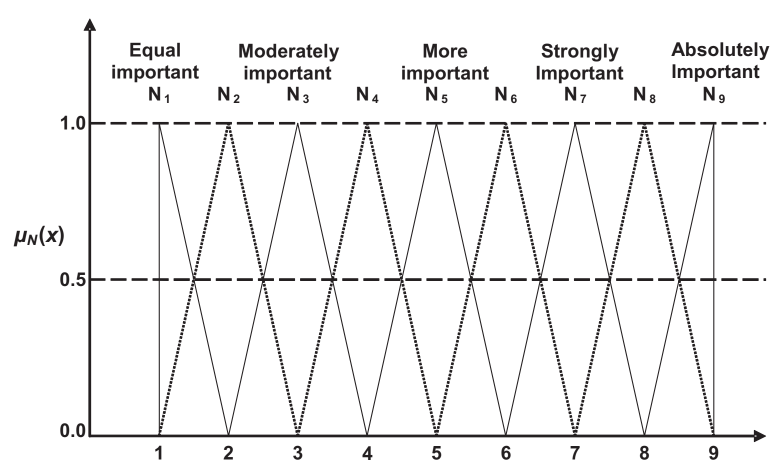

Figure A1. Membership functions of triangular fuzzy numbers.